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Ioffe Institute
6th Int. Symp. "Nanostructures: Physics and Technology"
St Petersburg, Russia, June 22–26, 1998.

Near-field radio-frequency modulated reflectance in semiconductor structures

A. O. Volkov and O. A. Ryabushkin
Institute of Radio Engineering and Electronics, Russian Academy of Sciences,
Fryazino, Moscow District, 141120, Russia, E-mail: aov228@ire216.msk.su

Abstract. In this paper we suggest Near-field configuration Radio-frequency Modulated light Reflectance technique (NRMR). NRMR spectra from GaAs/AlGaAs heterostructure were experimentally obtained. These spectra demonstrate a dramatic change in the reflectance. We have shown that the near-field radio-frequency perturbation are transferred along the heterostucture plane over extremely large distances which may be as large as several millimeters.

1 Introduction

Recently, Radio-frequency Modulated Reflectance (RMR) was proposed, as a novel optical modulation spectroscopy of semiconductor structures [1] and its great promise was shown at low temperatures with respect to traditional methods, such as photoluminescence (PL), electroreflectance and photoreflectance (PR). RMR principle is in the radio-frequency (rf) or microwave electric field effect on a light reflection from the structure. The effect of NRMR is due to influence of a local rf field formed by electrodes one of which is much smaller then rf wavelength on a heterostructure dielectric permeability. Being locally enhanced rf electric field excites the sample much stronger than in RMR case. Earlier we have observed a large lateral photo-perturbation propagation in GaAs/AlGaAs, registered by local PL and PR measurements [2]. The NRMR perturbation spreads far more than the photo-excited charges and fields do [2–4].

2 Experiment

We investigated GaAs/Al$_x$Ga$_{1-x}$As heterostructures with two dimensional electron gas grown by molecular beam epitaxy with parameters commonly used in high electron mobility transistors (Fig. 1). To provide near-field radio-frequency perturbation sample was placed between plane electrode (pel, 1 cm$\times$1 cm) and cylindrical electrode (cel, $\oslash$ 100 μm) (Fig. 2). 20 MHz rf voltage was applied. Amplitude of rf voltage was modulated at 2 kHz. Reflectance was measured by means of optical fibers F1 and F2. All experiments were carried out at the temperature $T = 77$ K, rf voltage 300 V and spectral resolution 0.7 meV.

Fig. 3 shows the scheme of the experimental set-up which we have used to investigate the NRMR effects (Fig. 3). Lamp (L) light is focused into the fiber F1. Receiving fiber F2 guides light reflected from the sample surface to the spectrometer. Photodetector (PD) registers both dc and ac signals. Then ac signal is processed bymeans of the lock-in amplifier, low-frequency generator (lf), rf high-voltage generator (rf) and time delay circuit (tD).

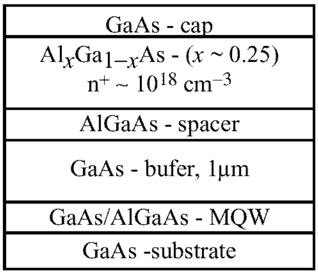

Fig. 1. Schematic cross section of modulation doped heterostructure.

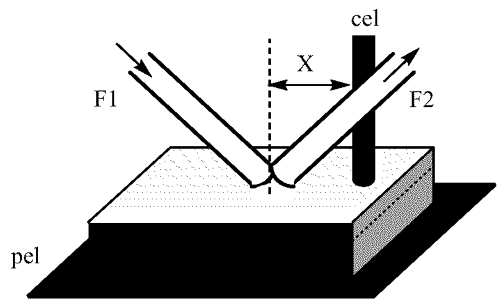

Fig. 2. Electrodes and optical fibers spatial arrangement.

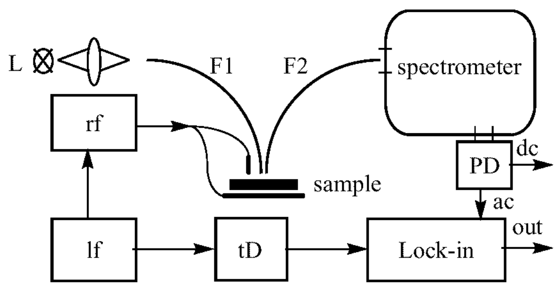

Fig 3. Experimental set-up.

3 Results and discussion

Fig. 4 shows the NRMR spectrum obtained when the probing light spot was separated from the cylinder electrode by the distance $X \sim 2$ mm. The change in the reflectivity exceeds 4% in the energy region of GaAs band gap (1.508 eV). RMR spectrum (multiplied by a factor 10 for comparison in Fig. 4) was formed at the same voltage as for NRMR but applied to capacitor plane electrodes producing homogeneous perturbation. RMR spectrum shape was described quantitatively by a model of [1] which takes into account the modulation of the internal homogeneous electric fields. But NRMR spectrum is obtained in strong non-homogeneous field. In this case NRMR spectrum shape is described qualitatively by model in [1] for interband transition near to M_0 critical point. The broadening of NRMR spectrum part at $E < E_g$ is explained by heating effects of two-dimensional electron gas in the external rf field.

Changing the probing light intensity from 1 mW/cm^2 to 100 mW/cm^2 did not modify the spectrum significantly. As the intensity was increased from 100 mW/cm^2 to 1 W/cm^2, respective optical response diminished and became non-linear with respect to rf amplitude. In the case of strong probing light intensity the out-of-phase component of NRMR response becomes considerable. Shown in Fig. 5 are two spectra (in one scale) obtained at the same external conditions. But the former (thin line) was obtained synchronously with the perturbation modulation signal, the latter (thick line) was obtained with 90° phase shift, which corresponds to 125 μsec time delay. It means that the heterostructure optical properties are changed with respect to rf perturbation appearance moment not only simultaneously but also with a some time delay. It validates

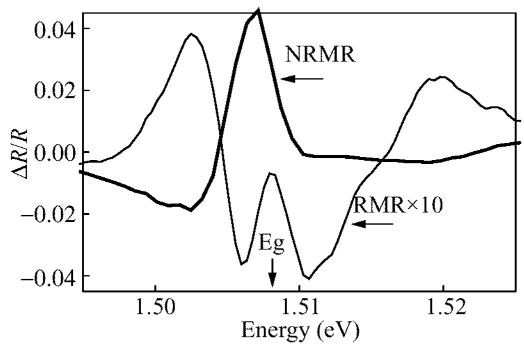

Fig 4. RMR and NRMR spectra, probing light intensity 1 mW/cm^2.

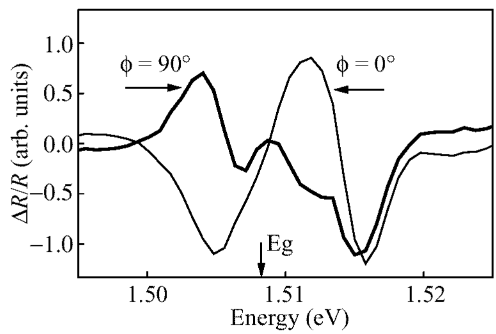

Fig 5. Phase dependence of NRMR spectrum with probe intensity 1 W/cm^2.

the multi-region GaAs buffer layer model suggested in [1]. Measuring the two NRMR spectra shifted one to another by phase of 90° permits one to investigate the charge carriers transposition in layer. Strong effect of modulated near-field on a light reflectance gives a new possibilities in the design of appropriate high-speed optical modulators, with reflected beam profile being controlled.

Acknowledgments

We would like to thank Sablikov V. A. for helpful discussions and encouragement in the course of this work.

This work is supported by Russian Foundation for Basic Research (grant 96-02-18476-a) and Russian Ministry of Science under the Program “Physics of solid state nanostructures” (grant 97-1054).

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